

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problem Mailbox.**



12-18-03

EXPRESS MAIL NO. EV336611308US

<b>TRANSMITTAL FORM</b>  (To be used for all correspondence after initial filing)	Application Number	10/648,776
	Filing Date	August 25, 2003
	First Named Inventor	Angelo Bosco
	Art Unit	
	Examiner Name	
	Attorney Docket No.	851063.485

ENCLOSURES (check all that apply)		
<input type="checkbox"/> Fee Transmittal Form <input type="checkbox"/> Fee Attached <input type="checkbox"/> Amendment/Response <input type="checkbox"/> After Final <input type="checkbox"/> Affidavits/declaration(s) <input type="checkbox"/> Extension of Time Request <input type="checkbox"/> Express Abandonment Request <input type="checkbox"/> Information Disclosure Statement; Form PTO-1449 <input type="checkbox"/> Cited References <input type="checkbox"/> Certified Copy of Priority Document(s) <input type="checkbox"/> Response to Missing Parts under 37 C.F.R. 1.52 or 1.53 <input type="checkbox"/> Response to Missing Parts/Incomplete Application	<input type="checkbox"/> Drawing(s) <input type="checkbox"/> Request for Corrected Filing Receipt <input type="checkbox"/> Licensing-related Papers <input checked="" type="checkbox"/> Petition <input type="checkbox"/> Petition to Convert to a Provisional Application <input type="checkbox"/> Power of Attorney, Revocation, Change of Correspondence Address <input type="checkbox"/> Declaration <input type="checkbox"/> Statement under 37 CFR 3.73(b) <input type="checkbox"/> Terminal Disclaimer <input type="checkbox"/> Request for Refund	<input type="checkbox"/> CD(s), Number of CD(s) _____ <input type="checkbox"/> After Allowance Communication to Group <input type="checkbox"/> Appeal Communication to Board of Appeals and Interferences <input type="checkbox"/> Appeal Communication to Group (Appeal Notice, Brief, Reply Brief) <input type="checkbox"/> Proprietary Information <input type="checkbox"/> Status Letter <input checked="" type="checkbox"/> Return Receipt Postcard <input checked="" type="checkbox"/> Additional Enclosure(s) (please identify below): <u>Declaration of David V. Carlson</u> <u>w/Exhibits A-F</u>
Remarks		

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT		
Individual Name	David V. Carlson	Customer Number
		00500
Signature		
Date	December 17, 2003	

CERTIFICATE OF TRANSMISSION/MAILING		
I hereby certify that this correspondence is being facsimile transmitted to the USPTO or deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date shown below.		
Typed or printed name		
Signature		Date:

This collection of information is required by 37 CFR 1.5. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450. 440923



EXPRESS MAIL NO. EV336611308US

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants : Angelo Bosco et al.  
Application No. : 10/648,776  
Filed : August 25, 2003  
For : METHOD FOR FILTERING THE NOISE OF A  
DIGITAL IMAGE SEQUENCE

Docket No. : 851063.485  
Date : December 17, 2003

Mail Stop Petition  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

PETITION TO CORRECT FILING DATE

Commissioner for Patents:

The applicants hereby petition to correct the filing date from August 25, 2003 to August 12, 2003.

On August 12, 2003, Applicants filed the above-referenced patent application in the United States Patent and Trademark Office. The filing was accomplished by mailing by U.S. Postal Service Express Mail the entire application together with the appropriate postage. At the time the application was filed, an Express Mail filing receipt was received officially stamped by the U.S. Postal Service indicating that it had been received on August 12, 2003. In addition, a handwritten date of August 12, 2003, at 10:05 p.m. also appears on the U.S. Postal Service receipt. The Express Mail label of the U.S. Postal Service matches the one typed on the top of the U.S. patent application as filed, which also appears on the return postcard and cover letter mailed in the envelope.

Applicants' attorneys accordingly mailed on August 12, 2003, by U.S. Express Mail, the patent application for filing in the U.S. Patent and Trademark Office. A declaration is attached, with evidence, to demonstrate such mailing.

To Applicants' surprise, on August 22, 2003, the envelope containing the patent application was returned to the Applicants' attorney in a very damaged condition. The package was extremely wet and dirty and some of the edges appeared to have been partially torn;

however, the package as a whole appeared to be intact and no documents had been removed. Because the damage done while in the hands of the U.S. Postal Service obliterated the address to which it was sent, it was returned to Applicants' attorney rather than mailed to the U.S. Patent and Trademark Office. As soon as Applicants received it, rather than open the envelope, we quickly filed a second application, which filing occurred on August 25, 2003.

Applicants have a foreign priority date of August 23, 2002. Since August 23, 2003 falls on a Saturday, the filing on August 25, 2003, appears to be within the priority deadline, however, Applicants did in fact file the application on August 12, 2003, and request that they be awarded this filing date.

Enclosed herewith is a Declaration by myself, David V. Carlson, providing exhibits and making affirmative statements regarding the facts and circumstances surrounding the mailing.

Applicants should be provided the filing date of August 12, 2003, because the application was in fact provided to the U.S. Postal Service with correct postage and in a timely fashion for delivery to the U.S. Patent and Trademark Office. The evidence of such delivery is enclosed herewith together with a Declaration and therefore Applicants are entitled to this date of August 12, 2003, and request that this petition be granted.

Applicants believe there is no fee due, however, the Director is authorized to charge any fee due by way of this Information Disclosure Statement to our Deposit Account No. 19-1090.

Respectfully submitted,

Seed Intellectual Property Law Group PLLC



David V. Carlson

Registration No. 31,153

DVC:lcs

Enclosures:

Postcard

Declaration of David V. Carlson w/Exhibits A-F

701 Fifth Avenue, Suite 6300

Seattle, Washington 98104-7092

Phone: (206) 622-4900

Fax: (206) 682-6031



EXPRESS MAIL NO. EV336611308US

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants : Angelo Bosco et al.  
Application No. : 10/648,776  
Filed : August 25, 2003  
For : METHOD FOR FILTERING THE NOISE OF A  
DIGITAL IMAGE SEQUENCE

Docket No. : 851063.485  
Date : December 17, 2003

Mail Stop Petition  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

DECLARATION OF DAVID V. CARLSON IN SUPPORT  
OF PETITION TO CORRECT FILING DATE

Commissioner for Patents:

I, David V. Carlson, declare and state that:

I am an attorney of record in this application and admitted to practice before the Patent and Trademark Office, Registration No. 31,153.

I, David V. Carlson, declare and state that:

Attached hereto as Exhibit A is a true copy of the Express Mail Post Office Receipt, customer copy. The customer copy of the Express Mail shows a received date of August 12, 2003, at the U.S. Postal Service. It also bears a handwritten check-in date of August 12, 2003, at 10:05 p.m. and has the initials of the acceptance clerk stated thereon. In addition, the full postage is noted as being paid. This is Express Mail label EV336610850 US. It is addressed to the Commissioner for Patents in Alexandria, Virginia. Enclosed as Exhibit B is a copy of the Utility Patent Application transmittal bearing my signature and a mailing date of August 12, 2003. Attached as Exhibit C is the application data sheet bearing in the upper right-

hand corner the same Express Mail number and stating the customer number, the title, and the inventors' names. Enclosed as Exhibit D is a copy of the utility patent application, with figures bearing in the top portion the same Express Mail label number EV336610850US as evidence that this is what was mailed on August 12, 2003.

Enclosed herewith as Exhibit E is the postcard which has stated thereon the Express Mail label together with the listing of the documents that are enclosed therewith.

Attached as Exhibit F is a photocopy of an Express Mail package received from the Post Office on August 22, 2003. In particular, the U.S. Postal Service returned to the law firm of Seed Intellectual Property Law Group the Express Mail package which had been entrusted to their care on August 12, 2003. The package was returned with the contents present but some corners and sides had been partially ripped and the envelope was extremely wet and dirty. It appears to have been dropped in a puddle outside or some other very wet environment. Accordingly, the address and information on the face of the label had been substantially obliterated by the rough handling by the United States Post Office such that it was returned to the sender.

Immediately upon receipt of the package on August 22, 2003, applicants prepared a second application and quickly filed a follow-up application on August 25, 2003, which contained a refiling of the same patent application.

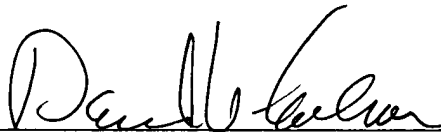
The Express Mail package which was returned in damaged condition has still not been opened, but it could be provided in the same form to the United States Patent and Trademark Office if they wish to receive it in its partially torn and still unopened condition.

Applicants formally request that the filing date of August 12, 2003, be accorded to the present application.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that the making of willfully false statements and

the like is punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and may jeopardize the validity of any patent issuing from this patent application.

Dated this 17<sup>th</sup> day of December, 2003.

A handwritten signature in dark ink, appearing to read "David V. Carlson", is written over a horizontal line.

David V. Carlson  
Registration No. 31,153

DVC:lcs

Enclosures:

Exhibits A-F

701 Fifth Avenue, Suite 6300  
Seattle, Washington 98104-7092  
Phone: (206) 622-4900  
Fax: (206) 682-6031

423164



Express Mail No.: EV336610850US

**APPLICATION DATA SHEET**

**Application Information**

Application number::  
Filing Date::  
Application Type:: Regular  
Subject Matter:: Utility  
Suggested classification::  
Suggested Group Art Unit::  
CD-ROM or CD-R?:: None  
Number of CD disks::  
Number of copies of CDs::  
Sequence submission?::  
Computer Readable Form (CRF)?:: No  
Number of copies of CRF::  
Title :: METHOD FOR FILTERING THE NOISE OF A  
DIGITAL IMAGE SEQUENCE  
Attorney Docket Number:: 851063.485  
Request for Early Publication?:: No  
Request for Non-Publication?:: No  
Suggested Drawing Figure::  
Total Drawing Sheets:: 6  
Small Entity?:: No  
Petition included?:: No  
Petition Type::  
Licensed U.S. Gov't Agency::  
Contract or Grant No::  
Secrecy Order in Parent Appl.?:: No

**EXHIBIT C**



**First Applicant Information**

Applicant Authority Type::	Inventor
Primary Citizenship Country::	Italy
Status::	Full Capacity
Given Name::	Angelo
Middle Name::	
Family Name::	Bosco
Name Suffix::	
City of Residence::	Giarre
State or Province of Residence::	
Country of Residence::	Italy
Street of mailing address::	Corso Matteotti, 20/B
City of mailing address::	Giarre
State or Province of mailing address::	
Country of mailing address::	Italy
Postal or Zip Code of mailing address::	I-95014

**Second Applicant Information**

Applicant Authority Type:: Inventor  
Primary Citizenship Country:: Italy  
Status:: Full Capacity  
Given Name:: Sebastiano  
Middle Name::  
Family Name:: Battiato  
Name Suffix::  
City of Residence:: Aci Catena  
State or Province of Residence::  
Country of Residence:: Italy  
Street of mailing address:: Via IV Novembre, 138/B  
City of mailing address:: Aci Catena  
State or Province of mailing address::  
Country of mailing address:: Italy  
Postal or Zip Code of mailing address:: I-95022

**Correspondence Information**

Correspondence Customer Number :: **00500**

**Representative Information**

Representative Customer Number::		<b>00500</b>
----------------------------------	--	--------------

**Domestic Priority Information**

Application ::	Continuity Type::	Parent Application::	Parent Filing Date::

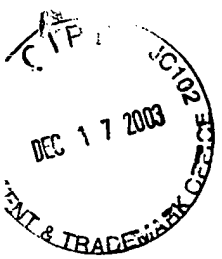
**Foreign Priority Information**

Country::	Application number::	Filing Date::	Priority Claimed::
Europe	02425532.5	08/23/02	Yes

**Assignee Information**

Assignee name::	STMicroelectronics S.r.l.
Street of mailing address::	Via C. Olivetti, 2
City of mailing address::	Agrate Brianza
State or Province of mailing address::	
Country of mailing address::	Italy
Postal or Zip Code of mailing address::	I-20041

404943 [9/19/01]



## METHOD FOR FILTERING THE NOISE OF A DIGITAL IMAGE SEQUENCE

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The present invention concerns the processing of digital images and,  
5 more particularly, a method for filtering noise in a digital image sequence.

#### Description of the Related Art

Digital images are currently being used in numerous applications, including those related with such traditional acquisition devices as still and video cameras. It is to be expected that ever greater use of digital images will be made  
10 in such new generation devices as mobile multimedia communication terminals.

There exist numerous devices or applications that use digital images in sequence, that is to say, images acquired one after the other, separated by a brief interval of time and representing approximately the same real scene.

The speed with which the sequence is acquired, *i.e.*, the number of  
15 images acquired in a given time interval, may vary according to the specific application; for example, this number is very large in digital video cameras (about 25 images per second) and smaller (about 15 images per second) in mobile communication terminals, which acquire the digital images and then transmit them in real time to a remote terminal.

20 It is well known that digital image acquisition devices, especially when they include CMOS sensors, will intrinsically introduce noise into the acquired images.

In digital image sequences noise not only degrades the quality of the images, but also reduces the encoding/compression efficiency. Indeed, the  
25 acquired image sequences have commonly to be encoded/compressed by means of encoding/compression techniques that operate in accordance with, for example,

the MPEG standard or the H263 standard and nowadays are very widely used in the greater part of devices in the market today.

The encoding/compression efficiency becomes reduced by the presence of noise, because the introduced noise is typically in the form of random  
5 fluctuations that reduce redundancy both within an image and between images that are temporally close to each other.

There exist numerous filtering techniques intended to reduce or eliminate the noise present in an image sequence.

Numerous attempts have been made to develop efficient techniques  
10 for reducing the noise of a sequence by using various specific types of filters. Known digital filters include, for example, low-pass filters, median filters, adaptive spatial filters and recursive temporal filters with or without motion compensation.

Other prior art techniques seek to improve noise reduction efficiency in image sequences by having recourse to hybrid methods that combine digital  
15 spatial filtering with digital temporal filtering.

Though the known techniques for reducing noise in image sequences are satisfactory in many respects, they are also associated with numerous drawbacks and problems that are bound up with, for example, inadequate performance, processing complexity and excessive processing costs  
20 that make it difficult to employ them in portable acquisition devices of a commercial type.

## BRIEF SUMMARY OF THE INVENTION

The present invention therefore sets out to make available a method for reducing noise in an image sequence. This aim is attained with a method for  
25 filtering a sequence of digital images in CFA format as described in Claims 1 to 12 attached hereto.

Another object of the present invention is to provide a filter as described in Claim 13 and an acquisition device as described in Claim 14.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Further characteristics of the invention and the advantages associated therewith will be more readily understood from the detailed description about to be given of a preferred embodiment thereof, which is to be considered as  
5 an example and not limitative in any way, said description making reference to the attached drawings of which:

Figure 1 shows the block diagram illustrating a possible acquisition device that implements a method in accordance with the present invention;

Figure 2 shows the pattern of the filtering elements of a Bayer sensor  
10 that can be used in the device of Figure 1;

Figure 3 schematically illustrates the succession of phases of a method in accordance with the present invention;

Figure 4 shows a selection mask for selecting green-colored pixels that can be employed in the method in accordance with the present invention;

15 Figure 5 shows two selection masks for selecting red-colored pixels and blue-colored pixels that can be employed in the method in accordance with the present invention;

Figure 6 shows one of the phases of the succession illustrated by Figure 3 in greater detail;

20 Figure 7 shows an example of selecting pixels in accordance with a DRT selection;

Figure 8 is a graph that illustrates the experimental results; and

Figure 9 is a schematic illustration of two filtering architectures, the first in accordance with the present invention, the second of a conventional type.

## 25 DETAILED DESCRIPTION OF THE INVENTION

The preferred embodiment example of the present invention relates to a portable device capable of acquiring digital image sequences for video

applications and, more particularly, concerns the noise filtering of an image sequence acquired with a digital video camera.

In this connection it should be noted that the teachings of the present invention can be extended also to applications other than those to which explicit  
5 reference is made in the description about to be given, for example, to the acquisition of image sequences in mobile multimedia communication terminals of the new generation.

Figure 1 provides a very schematic illustration of a digital video camera 1 in the form of function blocks. The video camera 1 includes an  
10 acquisition block 2 that comprises an optical sensor 3.

The optical sensor 3, which may be – for example - of the CCD (Charge Coupled Device) or the CMOS (Complementary Metal Oxide Semiconductor) type, is an integrated circuit comprising a matrix of photosensitive cells, each of which serves to generate an electrical signal proportional to the  
15 quantity of light that strikes it during the acquisition interval. Each photosensitive cell of the sensor, which is commonly referred to by the term pixel, corresponds to a respective pixel of the digital image.

In a preferred embodiment the sensor 3 comprises an optical CFA (Color Filter Array) filter, for example, with a Bayer-type matrix.

20 As is well known to persons skilled in the art, in a sensor with a CFA filter only a single photosensitive cell is available for acquiring a pixel. The sensor is covered by an optical filter constituted by a matrix (a Bayer matrix, for example) of filtering elements, each of which is associated with a photosensitive cell. Each filtering element transmits to the photosensitive cell associated with it the light  
25 radiation corresponding to the wavelength of only red light, only green light or only blue light, so that for each pixel it detects only one component (of which it absorbs no more than a minimal part). The pattern of the filtering elements in a Bayer filter is shown in Figure 2, where the letters R,G,B indicate, respectively, the red, green and blue elements.

The video camera 1 also includes an analog/digital (A/D) conversion block, indicated by the reference number 4, to translate the generated electric signal into a digital value with a predetermined number of bits (generally 8, 10 or 12 bits). One may assume, solely by way of example and without thereby  
5 introducing any limitation whatsoever, that in the present invention the A/D converter 4 is such as to encode the incoming analog signals with eight-bit digital values.

On the output side of the A/D block 4 the digital image is in a video format, for example, it may be in a CFA (Color Filter Array) format, since each pixel  
10 is constituted by just a single chromatic component (R, G or B). For this reason, a single one-byte digital value is associated with each pixel. In one embodiment, the digital image may be in the CFA format, but in other embodiments, other formats may be used and these are included within the concept of the invention. Thus, the reference to CFA herein should be understood to be one example of how to carry  
15 out the invention.

A filtering block 5 – in this example of the Bayer type – is such as to filter the noise by operating directly on the digital CFA images of the sequence, producing for each noisy CFA image on its input side a CFA image with reduced noise on its output side.

20 A pre-processing (PrePro) block 6, active before and during the entire acquisition phase, is such as to interact with the acquisition block 2 and to extract from the CFA image a number of parameters useful for carrying out automatic control functions: self-focusing, automatic exposure, correction of sensor defects and white balancing.

25 A block 7, the IGP (Image Generation Pipeline) block, is designed to perform a processing phase that, starting from the digital CFA image, will produce a complete digital image – YCrCb format, for example – in which each pixel will have associated with it three digital values (*i.e.*, a total of 24 bits) corresponding to a luminance component Y and two chrominance components Cr and Cb. This



transformation, known by the name of color interpolation, involves a passage from a representation of the image in a single plane (Bayer plane), which nevertheless contains information relating to different chromatic components, to a representation in three planes.

5                    In digital still cameras the IGP block is commonly realized in the form of a dedicated processor. In one embodiment, this is a CFA processor, which may be implemented in VLSI (Very Large Scale Integration) technology.

                    Preferably, the IGP block 7 in this example is also such as to perform, over and above the interpolation, various other functions, including – for  
10                    example – the application of special effects, gamma correction, scaling, stabilization and other functions that will generally vary from one producer to another.

                    This is followed by a compression/encoding block 8, which in this example is of the MPEG type (but could also be of other types, H263 for example),  
15                    and a memory unit 9.

                    When shooting a video sequence with the video camera 1, the sequence images are acquired consecutively by means of the acquisition block 2, preferably separated only by a brief time interval between one image and the next. The MPEG-4 standard, for example, requires fifteen images to be acquired per  
20                    second.

                    Hereinafter we shall use  $\text{Img}_1, \text{Img}_2, \text{Img}_3, \dots, \text{Img}_{n-1}, \text{Img}_n, \text{Img}_{n+1}, \dots$  to indicate the images acquired in sequence:  $\text{Img}_1$  represents the first image of the sequence to be acquired,  $\text{Img}_2$  represents the second image, and so on.

                    Following acquisition, each image is processed by the subsequent  
25                    blocks, so that in all the subsequent processing phases the images will still be processed in the temporal order in which they were acquired.

                    Once they have been acquired, the sequence images are converted into digital values by the A/D converter 4.

The CFA format digital images are then sent as input to the noise filter block 5 (CFA NF) to be processed in accordance with the noise filtering method of the present invention. As output the filter block produces a sequence of filtered CFA images, respectively,  $f\_img_1, f\_img_2, f\_img_3, \dots, f\_img_{n-1}, f\_img_n,$   
5  $f\_img_{n+1}$ , each of which has less noise than on the input side.

The filtered CFA images are then processed by the pre-processing block 6.

On leaving the pre-processing block 6, each CFA image is sent to the IGP block 7. In this block the images are subjected to a color interpolation  
10 phase and therefore transformed into complete images, for example, in YCrCb format.

The color interpolation phase may be performed, among others, by means of methods that are known to a person skilled in the art and are therefore obvious from the previous description.

15 Thereafter the images are sent to the MPEG encoder block 8, which produces as its output a sequence or stream of images encoded/compressed in accordance with an MPEG encoding.

The MPEG stream of compressed images may be recorded in a memory unit 9 or sent to an external peripheral device not shown in the figure.

20 In a preferred embodiment the processing method filters the sequence of CFA images one at a time, in this example by means of a Bayer filter.

The CFA images are filtered pixel by pixel, the scanning order being such that the pixels are systematically scanned from left to right and from top to bottom. In particular, for each pixel  $p_n(x,y)$  of an image  $img_n$  there is calculated a  
25 respective filtered homologous pixel  $f\_p_n(x,y)$  of a corresponding filtered image  $f\_img_n$ .

When processing the pixel  $p_n(x,y)$  of the image  $img_n$  and calculating the filtered pixel  $f\_p_n(x,y)$ , the method of the present invention makes advantageous use also of the filtered pixels forming part of an image  $f\_img_{n-1}$  of

the previously filtered sequence. More particularly, it utilizes the image  $f\_Img_{n-1}$  obtained by filtering the image  $Img_{n-1}$  that in the sequence temporally precedes the image to be filtered  $Img_n$ .

Typically, therefore, three image buffers will be sufficient for carrying  
5 out the filtering process: two input buffers that contain, respectively, the image  $Img_n$  to be filtered (current image) and the previously filtered image  $f\_Img_{n-1}$ , as well as an output buffer containing the filtered current image  $f\_Img_n$ .

Figure 3 shows a schematic representation of the succession of  
10 phases of a processing method 20 for reducing noise in accordance with the present invention.

In particular, Figure 3 shows the phases by means of which, starting from the pixel  $p_n(x,y)$  of the image  $Img_n$ , there is obtained the respective homologous filtered pixel  $f\_p_n(x,y)$  of the corresponding filtered image  $f\_Img_n$ .

Given the input pixel  $p_n(x,y)$  to be filtered, a first selection phase 21  
15 (SW\_sel) selects a first pixel set  $SW_n(x,y)$  comprising the said pixel  $p_n(x,y)$  and a plurality of pixels forming part of the image  $Img_n$  in the neighborhood of said pixel. In one embodiment, the phase selects adjacent pixels that have associated with them the same color (R, G or B) as the pixel to be filtered.

In a preferred embodiment, the selection is performed by using  
20 selection masks (or matrices)  $SM\_G$ ,  $SM\_R$ ,  $SM\_B$  that differ on the basis of the color of the pixel  $p_n(x,y)$  to be filtered, but all of dimension  $5 \times 5$ , for example, like those shown in Figures 4 and 5.

Figure 4 shows a selection mask  $SM\_G$  for the green pixels (G) in  
accordance with a particular embodiment of the invention. In the selection phase  
25 21 the mask  $SM\_G$  is aligned with the image to be filtered in such a way that that  $G_0$  corresponds to the green pixel  $p_n(x,y)$  to be filtered. In this way the mask  $SM\_G$  will select a first set of pixels  $SW_n(x,y)$  comprising the green pixel  $p_n(x,y)$  corresponding to  $G_0$  and eight adjacent pixels situated, respectively, in positions

corresponding to the pixels  $G_1, \dots, G_8$  of the mask  $SM\_G$  shown in the figure. This set defines a spatial working window  $SW_n(x,y)$  for the green pixel to be filtered.

Analogously, Figure 5 shows the selection masks  $SM\_R$  and  $SM\_B$  to be used, respectively, when the pixels to be filtered are red or blue.

5                   The mask  $SM\_R$  for the red pixels is such as to select a first set of pixels  $SW_n(x,y)$  comprising the red pixel  $p_n(x,y)$  to be filtered corresponding to  $R_0$  and eight adjacent red pixels situated, respectively, in positions corresponding to the pixels  $R_1, \dots, R_8$  of the mask.

                  It should be noted that in this particular embodiment the selection  
10   mask  $SM\_B$  for the blue pixels is identical with the selection mask  $SM\_R$  for the red pixels. This choice is possible thanks to the particular pattern in which the filtering elements are arranged in a Bayer-type sensor.

                  This brings with it the advantage that the selection phase 21  
15   ( $SW\_sel$ ) has to discriminate only between two possible cases, namely to distinguish whether the pixel  $p_n(x,y)$  to be filtered is or is not green.

                  Coming back to Figure 3, a second selection phase 22 ( $TW\_sel$ ) selects a second set of pixels  $TW_n(x,y)$ , comprising pixels forming part of the previously filtered image  $f\_Img_{n-1}$  and arranged in corresponding positions, *i.e.*, homologous with the pixels of the first  $TW_n(x,y)$ .

20                   To this end it will be advantageous to use the selection matrices described above, but this time applied to the previously filtered image  $f\_Img_{n-1}$ .

                  The pixel set obtained in this manner defines a temporal working window  $TW_n(x,y)$  for the pixel to be filtered.

                  The temporal and spatial working windows represent the set of pixels  
25   that will play a part in the subsequent phases of the filtering process of the pixel  $p_n(x,y)$ .

                  As is well known to a person skilled in the art, when digital image sequences are filtered, a filtered pixel can be obtained by appropriately combining

a certain number of pixels that are adjacent to it either in space (spatial filtering), in time (temporal filtering) or in space/time (spatio-temporal filtering).

In particular, as will be described in greater detail later on, the method of the present invention decides pixel by pixel whether the filtering to be  
5 used is to be exclusively spatial or, on the other hand, spatio-temporal.

Advantageously, the decision regarding the type of filtering to be employed will be bound up with the amount of motion between successive images of the sequence, since this will make it possible to avoid motion compensation, a computationally very costly operation.

10 When spatial filtering is employed, the operation will involve only the pixels of the spatial working window  $SW_n(x,y)$ , otherwise use will be made of the pixels forming part of both the windows.

Once the two working windows – respectively in space and time – have been obtained, a first noise estimation phase 23 (Snoise\_est) has as its first  
15 step the making of an estimate of a statistical parameter  $NL_n(x,y)$  representative of the noise level present on the pixel  $p_n(x,y)$  and the respective spatial working window  $SW_n(x,y)$ . Henceforth we shall refer to this noise as spatial noise, while the phase will be referred to as spatial noise estimation.

In greater detail, the first step of the estimating phase 23  
20 (Snoise\_est) is to make a preliminary noise estimate (*i.e.*, to estimate a statistical parameter representative of the noise level) by means of a local calculation, that is to say, calculated for the pixels of the spatial working window  $SW_n(x,y)$ . As second step it obtains the definitive spatial estimate  $NL_n(x,y)$  by modifying the preliminary estimate on the basis of a spatial estimate of the noise specific for the color of the  
25 pixel to be filtered and specific also for the image  $Img_n$ .

In greater detail, again, the spatial noise estimate is obtained by means of a computation of the recursive type that is made by taking into account not only a preliminary and local noise calculation, but also the spatial estimate of

the noise level made for the last filtered pixel of the image  $\text{Img}_n$  having the same color as the pixel to be filtered  $p_n(x,y)$ .

Stated in mathematical terms, in the case in which, for example,  $p_n(x,y)$  is a green pixel, we have:

$$5 \quad NL_n(x,y) = NL_n^G(x,y) = k_n(x,y) \times N[SW_n(x,y)] + (1 - k_n(x,y)) \times NL_n^G(pp^G) \quad (1)$$

where the superscript "G" indicates that the term relates to the color green,  $N[SW_n(x,y)]$  is the preliminary estimate calculated for the spatial working window  $SW_n(x,y)$ ,  $k_n(x,y)$  is a multiplication factor comprised between zero and one and determines the strength of the spatial filter,  $NL_n^G(pp^G)$  is the spatial noise estimate  
10 made for the green pixel  $pp^G$  of the image  $\text{Img}_n$  that immediately precedes the green pixel to be filtered  $p_n(x,y)$  in the order in which the image  $\text{Img}_n$  is scanned.

Obviously, if the pixel to be filtered  $p_n(x,y)$  is the first pixel of the respective color to be filtered in the image  $\text{Img}_n$ , only the preliminary estimate  $N[SW_n(x,y)]$  will be available. In that case we can either put, for example,  
15  $k_n(x,y)=1$  solely for the pixel  $p_n(x,y)$  or, alternatively, assign an arbitrary and preferably small value to the quantity  $NL_n^G(pp^G)$ .

The first phase of the spatial noise estimation 23 (Snoise\_est) may be carried out, for example, as described in detail in European Patent Application No. 01830562.3 filed in the name of the present applicant, which is to be deemed  
20 to be wholly incorporated herein by reference. The meaning of the quantities  $NL_n(x,y)$ ,  $N[SW_n(x,y)]$ ,  $k_n(x,y)$ ,  $NL_n^G(pp^G)$  and the manner in which they are calculated are likewise explained in that document. In this connection please refer to formulas (1), (2), (3), (4), (5), (6), (7), (8) and Figures 7, 8A, 8B, 10 (and the descriptions relating thereto) of the aforesaid patent application No. 01830562.3.  
25 For further details of the spatial noise estimation as described hereinabove, especially as expressed in equation (1), reference should also be made to US Patent 6,108,455.

The spatial noise estimate  $NL_n(x,y)$  as calculated in this manner is used for regulating the degree or strength of the filtering in the case in which the filtering of the pixel  $p_n(x,y)$  is exclusively of the spatial type.

Once the spatial noise estimation phase of Snoise\_est 23 has been  
5 completed, a subsequent inhomogeneity estimation phase Text\_est associates an inhomogeneity index (or "texture" degree)  $T_D(x,y)$  with the pixel to be filtered  $p_n(x,y)$  on the basis of a measure of the inhomogeneity (or, analogously, of the homogeneity) of the pixels forming part of the spatial working window  $SW_n(x,y)$ .

The inhomogeneity index  $T_D(x,y)$  serves to decide whether the pixel  
10  $p_n(x,y)$  does or does not form part of a homogeneous region, this with a view to establishing whether or not the pixel in question (and therefore the corresponding spatial working window) will have to contribute to a spatio-temporal noise estimate to be described in greater detail further on.

In fact, a homogeneous region can provide reliable information about  
15 the effective noise present in the image, because the fluctuations (*i.e.*, the differences) between pixels forming part of a homogeneous region are substantially to be attributed to random noise.

Persons skilled in the art are familiar with different metrics for calculating an inhomogeneity measure associated with a set of pixels, and for this  
20 reason we shall not here delve further into this matter. Among these metrics we shall here cite the following solely by way of example: maximum difference, minimum difference, MAD (Mean of the Absolute Differences), standard deviation, extraction of a distribution parameter from a histogram of the digital values of the pixels.

25 In an embodiment that is particularly advantageous from a computational point of view, the parameter  $k_n(x,y)$  used in the spatial noise estimation phase 23 (Snoise\_est) is calculated on the basis of an inhomogeneity/homogeneity measure. More particularly, it is obtained on the basis of a calculation of the differences between the pixel to be filtered and the

other pixels of the spatial working window. In that case the inhomogeneity estimation phase 24 (Text\_est) can be inserted in the spatial noise estimation phase 23 (Snoise\_est) by calculating a single inhomogeneity measure that can be used both for estimating the spatial noise and for associating an inhomogeneity index  $T_D(x,y)$  with the pixel to be filtered.

A comparison phase 25 is used to verify whether the inhomogeneity index  $T_D(x,y)$  of the pixel  $p_n(x,y)$  is smaller than a predetermined threshold value  $T_h$  (i.e., whether the pixel forms part of a region deemed to be homogeneous).

Namely, when the inhomogeneity index  $T_D$  is smaller than a threshold  $T_h$ , there is a local noise estimation phase 26 before the motion detection phase 27, but if  $T_D$  is larger than  $T_h$ , there is a motion detection phase 27 immediately after the comparison phase.

If this is not the case, the next step is the motion detection phase 27 (Mot\_det). But if the pixel forms part of homogeneous region, the motion detection phase 27 is preceded by a second local noise estimation phase 26 (L\_STnoise\_est), i.e., performed on the pixel to be filtered, that serves to obtain a global noise estimate (i.e., for the entire image that is being processed).

The local noise estimation phase 26 (L\_STnoise\_est) estimates a parameter - which may be statistical, for example - representative of the noise locally present in the spatial working window. This parameter is calculated, for example, as a local standard deviation  $\sigma_{n+1}^{Loc}$  of the spatial working window of the pixel  $p_n(x,y)$  or as some other analogous energy measure.

Given the spatial working window  $SW_n(x,y)$  of the pixel  $p_n(x,y)$ , the local standard deviation  $\sigma_{n+1}^{Loc}$  can be calculated in accordance with the following formula:

$$\sigma_{n+1}^{Loc}(x,y) = \sqrt{\frac{1}{N-1} \sum_{(x,y) \in SW_n(x,y)} (p_n(x,y) - m)^2} \quad (2)$$



where  $N$  is the number of pixels forming part of the spatial working window  $SW_n(x,y)$  (in this case  $N=9$ ) and  $m$  is the mean of the digital values of these pixels.

As already mentioned (and as is to be explained in greater detail further on), once the filtering of the image  $Img_n$  has been terminated, the various  
5 local standard deviations  $\sigma_{n+1}^{Loc}$  calculated in this manner for the pixels of the image  $Img_n$  that are deemed to form part of homogeneous regions will be used for updating a global noise estimate  $\sigma_{n+1}^{GL}$ , which we shall hereinafter refer to also as spatio-temporal noise estimate. In particular, this global estimate will be used for the spatio-temporal filtering of the subsequent image  $Img_{n+1}$ .

10 The movement detection phase 27 (Mot\_det) compares the pixels of the temporal working window  $TW_n(x,y)$  with the pixels of the spatial working window  $SW_n(x,y)$  in order to ascertain the presence of motion between the two working windows and possibly evaluate its magnitude.

As is well known to a person skilled in the art, when using a “non-  
15 compensated motion” approach, appropriate precautions have to be taken to avoid the introduction during the spatio/temporal filtering of artifacts due to the motion between consecutive images. In particular, care must be taken to assure that the two working windows will not contain incongruent data on account of the motion between consecutive images or parts of them.

20 For example, it may happen that one working window contains pixels that form part of an object, while the other window contains pixels that form part of the background, because the object has moved between one image and the next.

Typical examples of artifacts that could be produced in these cases are the presence of troublesome trails and so-called “ghost images” that become  
25 visible in the filtered image due to residual information of previous images.

In a preferred embodiment, the motion detection phase (Mot\_det) calculates as measure of motion a measure  $M(x,y)$  that is the sum of the absolute differences (SAD) between the pixels of the temporal working window and the pixels of the spatial working window. The greater the differences between the two



When this is the case, the system concludes that there is excessive change between the two working windows and the subsequent filtering phase 29 (S\_filter) is therefore exclusively of the spatial type.

The exclusively spatial filtering produces the filtered pixel  $f_{p_n}(x,y)$  from the pixels of the spatial working window. The strength of the filtering is regulated by the estimate of the spatial noise level  $NL_n(x,y)$  calculated in noise estimation phase 23 (Snoise\_est). In a preferred embodiment, the spatial digital filtering is carried out in accordance with the technique described in the previously mentioned European Patent Application No. 01830562.3, which obtains the filtered pixel as a weighted average (mean) of the pixels of the spatial working window (see, in particular, formula (9) of said application).

Obviously, the exclusively spatial filtering is also carried out for all the pixels of the first image of the sequence, because temporal data are not yet available in this case.

On the other hand, when the motion measure  $M(x,y)$  is smaller than the predetermined threshold value  $M_h$ , the subsequent filtering phase 30 (ST\_filter) is of the spatio/temporal type and is illustrated in greater detail in Figure 6.

ST\_filter 30 consists of a first filtering phase 33 (Duncan\_Filt), which produces a provisional filtered pixel  $d_{p_n}(x,y)$  in accordance with a filtering technique that is known by the name of Duncan filtering and will be described in greater detail further on. In this phase the provisional filtered pixel  $d_{p_n}(x,y)$  is obtained from a subset of pixels forming part of both the working windows.

As can be seen in Figure 6, when the detected motion is deemed to be sufficiently small, i.e., smaller than a further predetermined threshold value  $M_l$  that is smaller than the threshold value  $M_h$ , the provisional filtered pixel is not subjected to any further processing and one simply puts:

$$f_{p_n}(x,y) = d_{p_n}(x,y) \quad (4)$$

In this case, therefore, the pixel  $p_n(x,y)$  is effectively filtered by means of a Duncan spatio/temporal filtering method.

Vice versa, *i.e.*, in the case in which the detected motion is not negligible, the provisional pixel  $d\_p_n(x,y)$  is subjected to a further processing phase  
5 35 (Smooth\_Filt), which produces the “definitive” filtered pixel  $f\_p_n(x,y)$  in accordance with a smoothing operation as defined by the following formula:

$$f\_p_n(x,y) = \beta_n \times d\_p_n(x,y) + (1 - \beta_n) \times p_n(x,y) \quad (5)$$

where  $\beta_n$  is a multiplying factor comprised between 0 and 1 that may either depend on the motion measure  $M(x,y)$  or may be the same for all the images of the  
10 sequence. In a preferred embodiment, for example,  $\beta_n$  is equal to about 0.75.

Following the smoothing operation, the definitive filtered pixel is obtained from a portion (in this example 75%) of the value provided by the Duncan filtering and a portion (25%) of the value of the unfiltered pixel. In other words, the definitive filtered pixel is obtained from the sum of a fraction of the provisional  
15 filtered pixel and a fraction of the unfiltered pixel.

This is done because, whenever there are non-negligible incongruencies due to motion between the working windows, it is important that one should be able to “neglect” the temporal information to a somewhat greater extent and attribute a little more importance to the current image that is being  
20 filtered.

We shall now describe a particularly advantageous embodiment of the Duncan filtering phase.

Duncan filtering first selects a subset or “range” of pixels forming part of the two working windows by means of the so-called “Duncan Range Test” or  
25 “DRT” (in this connection see “Multiple range and multiple f-tests”, D.B. Duncan, Biometrics, vol. 11., pp. 1-42, 1955).

The application the DRT to digital filtering is known, for example, from European Patent Application EP 1 100 260 A1 by the present applicant.

The subsequent filtering operations of the pixel  $p_n(x,y)$  are then performed only on the pixels that form part of the range selected by means of the DRT.

The purpose of the selection effected by means of the DRT is to  
5 exclude any pixels that, though forming part of the working windows, have had their value corrupted to an excessive extent by noise.

For example, such pixels may be present due to the effect of a particular noise – known as “salt and pepper noise” – capable of bringing the digital values of some pixels up to the maximum value or down to the minimum  
10 value of the scale of the possible digital values.

Selection by means of the DRT is also intended to exclude any pixels that are very different from the pixel to be filtered  $p_n(x,y)$ , for example, on account of a different information content. One may think, for example, of the case in which the pixel to be filtered  $p_n(x,y)$  forms part of an “edge”, while the working  
15 windows contain pixels that form part of the background of the scene. If the background pixels were not excluded, the image would suffer a considerable loss of definition as a result of the filtering.

A selection made by means of the DRT has to identify a digital value interval SI (selection interval) having an appropriate width S such as to contain the  
20 largest possible number of pixels (in this case forming part of the working windows) similar to the pixel to be filtered  $p_n(x,y)$ . The width S of the selection interval SI is correlated with the standard deviation of the noise to be filtered, which is assumed to be known.

It is not necessary for this interval to be centered around the pixel to  
25 be filtered: if this were to be the case and if the pixel to be filtered were, for example, highly corrupted by noise, the test would exclude pixels useful for the filtering.

In a preferred embodiment, the noise standard deviation used for the DRT selection during the filtering of the pixel  $p_n(x,y)$  of the image  $Img_n$  is the global

spatio/temporal noise estimate  $\sigma_n^{GL}$  calculated in the filtering of the previous image  $Img_{n-1}$ . This choice is particularly advantageous from the point of view of computational resource optimization: in this way, in fact, one avoids having to carry out a complete scanning of the image  $Img_n$  that is to be filtered (an operation that  
5 serves only to estimate the noise) prior to the filtering in the proper sense of the term.

The theory of DRT selection provides all the instruments needed for calculating the width  $S$  from the standard deviation of the noise and determining the optimal selection interval  $SI$ . The implementation of these instruments,  
10 however, is very costly in computational terms and cannot readily be conciliated with the stringent requirements imposed by real-time image processing.

In a preferred embodiment, an optimal compromise between reliability of the result and computational complexity is obtained by performing the selection of the pixel subset with one of the following three intervals  $SI1$ ,  $SI2$ ,  $SI3$ ,  
15 as shown in Figure 7, where:

- the interval  $SI1$  of width  $S$  is centered around the digital value  $DV$  of the pixel to be filtered  $p_n(x,y)$ ;
- the interval  $SI2$  of width  $S$  is centered around the digital value  $DV = p_n(x,y) + \sigma_n^{GL}$ ;
- 20 • the interval  $SI3$  of width  $S$  is centered around the digital value  $DV = p_n(x,y) - \sigma_n^{GL}$ .

The interval to be chosen from among these three intervals  $SI1, SI2, SI3$  is the one that contains the largest number of pixels, which in Figure 7 is the interval  $SI1$ . In this way good results are obtained even when the pixel to be  
25 filtered  $p_n(x,y)$  is a very noisy pixel.

Still in a preferred embodiment, moreover, the width  $S$  of the selection interval  $SI$  is calculated as:

$$S = 3 \times \sigma_n^{GL} \quad (6)$$

In a variant that is computationally costlier but yields optimized performances, the choice of the selection interval is made by using appropriate weighting functions in accordance with the method described in the aforementioned European Patent Application EP 1 100 260 A1 (where particular  
5 reference should be made to Figures 1b and 4).

Once the pixels  $P_j$  most similar to the pixel to be filtered and contained in the two working windows and the selection interval SI have been identified by means of the DRT, the provisional filtered pixel  $d\_p_n(x,y)$  is calculated as the weighted mean of these pixels or, put in mathematical terms:

$$10 \quad d\_p_n(x,y) = \sum_{P_j \in SI} a_j P_j \quad (7)$$

where, preferably, the weighting coefficients  $a_j$  are calculated as in the aforementioned European Patent Application EP 1 100 260 A1 (where particular reference should be made to page 6, lines 41-50).

Coming back to Figure 3, the filtering – which, as previously  
15 explained, takes place in accordance with either phase 29 (S\_filter) or phase 30 (ST\_filter) – is followed by a control phase 31 that checks whether the pixel  $p_n(x,y)$  that has just been filtered is the last pixel of the image  $Img_n$ . If  $p_n(x,y)$  is not the last pixel, the method represented as a succession of phases in Figure 3 is applied to the next pixel in the scanning order, for example, the pixel  $p_n(x,y+1)$ .

20 When it is the last pixel, on the other hand, there follows a global noise estimation phase of the spatio-temporal type based on the numerous local estimates  $\sigma_{n+1}^{Loc}$  calculated for the pixels of the image  $Img_n$  deemed to form part of homogeneous regions during the local noise estimation phase 26. In particular, these estimates are used to update a global noise estimate  $\sigma_{n+1}^{GL}$  of the spatio-  
25 temporal type that will subsequently be used in the spatio-temporal filtering of the next image  $Img_{n+1}$ . Preferably, the global estimate  $\sigma_{n+1}^{GL}$  should be representative

of the standard deviation of the noise and be calculated as the mean of the numerous local estimates (standard deviations)  $\sigma_{n+1}^{Loc}$ .

In some situations it may however happen that adjacent images have excessively discordant values of the global standard deviation  $\sigma_{n+1}^{GL}$  and the spatio-temporal filtering could therefore filter adjacent images with intensities that are too widely different. This would give rise to a bothersome flickering in the reproduction of the sequence.

With a view to avoiding this drawback, a preferred embodiment modifies the global standard deviation  $\sigma_{n+1}^{GL}$ , originally calculated as the mean of the local standard deviations, by obtaining a time average in a recursive manner of a certain number (for example: two) of global standard deviations  $\sigma^{GL}$  relating to consecutive images. Put in mathematical terms, we thus have:

$$\sigma_{n+1}^{GL} = \gamma \times \sigma_{n+1}^{GL} + (1 - \gamma) \times \sigma_n^{GL} \quad (8)$$

where  $\gamma$  is a number comprised between 0 and 1,  $\sigma_n^{GL}$  is the global noise estimate as updated during the filtering of the previous image  $\text{Img}_{n-1}$  and used in the spatio-temporal filtering of the current image  $\text{Img}_n$ . For example, the number  $\gamma$  may be equal to about 0.75.

We shall now describe some embodiments alternative to the particular method described hereinabove by reference to Figure 3.

As compared with Figure 3, the motion detection block 27 (Mot\_det) of one of these embodiment variants limits itself to detecting the presence/absence of motion and as output provides a binary measure  $M(x,y)$  indicative of the presence/absence of motion. For example, the output may be  $M(x,y)=1$  when the presence of motion is detected, otherwise the output will be  $M(x,y)=0$ . In this case the value of the threshold  $M_h$  may be chosen, for example, as equal to 0.5.

Phase 24 (Mot\_det) may detect the presence of motion by means of a "trail detection" method that operates by simply calculating the differences the two working windows pixel by pixel. If these differences all have the same sign, be



it positive or negative, the system detects the presence of motion, otherwise it detects the absence of motion.

When the presence of motion is detected, the next step is the previously described spatial filtering phase 29.

5                   In the contrary case, *i.e.*, when no motion is detected, this is followed by a spatio-temporal filtering phase 30 (ST\_filter) in which the filtered pixel is obtained by means of a Duncan filtering phase 33 (Duncan\_Filt) – see Figure 6 – that may or may not be followed by a phase of smoothing filtering 35 (Smooth\_Filt).

10                   In yet another embodiment variant, the two filtering phases 29 and 30 (S\_filter and ST\_filter), which are, respectively, a spatial filtering and a spatio-temporal filtering, obtain the weighted means for calculating the filtered pixel  $f_{pn}(x,y)$  by replacing some of the pixels that form part of the weighted mean by their respective filtered values whenever this value is already available in the  
15                   output buffer.

Experimental results have shown that the proposed filtering method is capable of providing concrete advantages in terms of both image quality and encoding/compression efficiency, and this notwithstanding the fact that it calls for the allocation of only modest computational and memory resources. This renders  
20                   use of the method of the present invention particularly advantageous in applications that call for real-time processing capacity.

Referring to Figure 8, the curve denominated “CFA\_filtered” reproduces, image by image, a quality measure for a sequence of three hundred images that were filtered in accordance with the present invention. The measure  
25                   was obtained from filtered and interpolated images.

The second curve in Figure 8, indicated by the denomination “Noisy”, reproduces the same measure as obtained on the same sequence prior to filtering; in this case, once again, the measure was obtained from interpolated images.

The results of Figure 8 refer, in particular, to a measure known as PSNR (Peak-to-Peak Signal to Noise Ratio). The PSNR is a standard measure and is representative of the quality of an image; more particularly, it indicates the signal quantity present in an image as compared with the quantity of noise.

5           The results of Figure 8 show that the filtered sequence is characterized by a higher PSNR measure (the gain is typically of the order of 3 dB), which is indicative of a better quality.

Figure 9 shows two processing schemes that can be used for obtaining a sequence of filtered images encoded/compressed in accordance with  
10 the MPEG4 standard from a sequence of noisy CFA images.

More particularly, in the first of the two procedures, here denominated E1, the CFA images are filtered by means of a method in accordance with the present invention by the filter 5 (CFA NF), after which they are interpolated by the block 7 (IGP) and encoded/compressed by the block 8 (MPEG4-Encoder).

15           In the other procedure, here denominated E2, the noisy CFA images are first interpolated by the block 7 (IGP), after which – following a conventional filtering scheme – they are filtered by means of a filtering method with motion compensation immediately prior to MPEG encoding/compression in Block 8, this method being indicated as MC\_NF. In particular, the MC\_NF method uses the  
20 motion estimate and the motion compensation of the MPEG encoder to perform a spatio-temporal digital filtering with motion compensation.

Experimental results have shown that processing procedure E1, *i.e.*, the one in accordance with the present invention, makes it possible to obtain a gain of 20% in terms of bit rate with respect to the conventional procedure E2.

25           This can be explained by considering the fact that processing procedure E2 estimates the motion and the motion compensation from images that are affected by noise and cannot therefore furnish an optimal result, with consequent adverse effects as regards both image quality and compression efficiency.

The filtering method in accordance with the invention, which has been described hereinabove by reference to a preferred embodiment, can be implemented by utilizing hardware, software or a combination of hardware and software. In the latter case the method may be implemented in an application-specific integrated circuit (ASIC circuit).

When it is implemented in a device for acquiring image sequences, the method in accordance with the present invention can be advantageously carried out by means of processing resources (DSP, for example) shared with other applications within the said device.

Obviously, a person skilled in the art, especially when having to satisfy contingent and specific needs, could introduce numerous modifications and variants into the proposed method of filtering a digital image sequence, though without thereby overstepping the protection limits of the invention as defined by the claims set out hereinbelow.

All of the above U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, are incorporated herein by reference, in their entirety.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

## CLAIMS

1. A method for filtering the noise of a sequence of digital images in video format comprising the following phases:

processing a first video image of the sequence to obtain a corresponding improved video image with reduced noise;

processing at least one pixel of a second video image of the sequence that temporally follows said first image, said phase of processing at least one pixel providing a corresponding filtered pixel and including the following operations:

selecting a first set of pixels comprising said at least one pixel and a plurality of pixels of the second video image spatially adjacent to it;

selecting a second set of pixels comprising pixels of the improved video image homologous with the pixels of said first set;

carrying out a digital filtering of a first type using pixels forming part of said first and second set to generate the filtered pixel.

2. A method in accordance with Claim 1, comprising also a phase of:

carrying out a first evaluation of motion of the at least one pixel, using pixels forming part of said first and second set; and in which said at least one pixel is such that said evaluation of motion is smaller than a first threshold value.

3. A method in accordance with Claim 1, comprising also a phase of:

processing a further pixel of said second image, said phase of processing the further pixel providing a corresponding further filtered pixel and including the following operations:

selecting a third set of pixels comprising said further pixel and a plurality of pixels of the second video image spatially adjacent to it;

selecting a fourth set of pixels comprising pixels of the improved video image homologous with the pixels of said third set;

carrying out a further evaluation of motion of the further pixel, using pixels forming part of said third and fourth set;

whenever said further evaluation of motion is smaller than said first threshold value, carrying out a digital filtering of a second type that generates the further filtered pixel by using exclusively pixels forming part of said third set.

4. A method in accordance with Claim 1, wherein each video image of the sequence is made up of a respective pixel matrix, the pixels of said matrix being associated on the basis of their respective positions with one of a set of chromatic components, and wherein said first and second set comprise pixels associated with the same chromatic component of the at least one pixel.

5. A method in accordance with Claim 4, wherein the images of the sequence are in Bayer CFA format and said chromatic components form part of the set comprising the color red, the color green and the color blue.

6. A method in accordance with Claim 5, wherein the phase of selecting the first set of pixels is carried out by means of selection matrices that differ according to the chromatic component of the at least one pixel, the selection matrices being such as to select pixels that are situated in the neighborhood of the at least one pixel and having the same chromatic component as said at least one pixel, discarding the others, the selection matrices being also identical for the chromatic components red and blue.

7. A method in accordance with Claim 1 that includes also a phase of making an estimate a statistical parameter  $\sigma_n^{GL}$  representative of the global noise present in said first image ( $Img_{n-1}$ ), the digital filtering of the first type utilizing also said statistical parameter.

8. A method in accordance with Claim 7, comprising also the following phases:

selecting a plurality of pixels of the first image;

calculating a plurality of local estimates, calculating for each given pixel of said plurality of pixels a respective estimate of a statistical parameter representative of the local noise in present in a neighborhood of the given pixel; and wherein said estimate of the statistical global noise parameter  $\sigma_n^{GL}$  is obtained from said plurality of local estimates.

9. A method in accordance with Claim 8, wherein said local estimates are local variance measures.

10. A method in accordance with Claim 8, wherein said plurality of pixels comprises pixels forming part of homogeneous regions of the first image.

11. A method in accordance with Claim 1, wherein said digital filtering of the first type utilizes a subset of pixels forming part of said first and said second set of pixels, said subset being identified by means of a further selection phase carried out in accordance with a Duncan Range Test.

12. A method in accordance with Claim 3, comprising also a phase of estimating for the further pixel a further statistical parameter representative of the noise present on the pixels of said third set, said further parameter estimated also on the basis of the specific color of the further pixel, the digital filtering of the second type utilizing said further parameter.

13. A filter for reducing the noise of a sequence of images in CFA format, characterized in that said noise reduction is obtained by means of a method in accordance with claim 1.

14. An acquisition device for acquiring a sequence of digital images in CFA format, comprising a sensor for acquiring said images, said sensor comprising a CFA filter, characterized in that the sequence of images in CFA format is processed by means of a noise filtering method in accordance with claim 1.

15. A method of filtering noise from a digital video image comprising:  
processing a first image to generate an improved image;  
processing a second, subsequent image;  
selecting a first pixel from the second image during the processing of the second image;  
selecting a first set of pixels in the second image that are a predetermined spatial relationship to the first pixel;  
locating a corresponding second set of pixels in the first image that correspond to the first set of pixels in the second image; and  
filtering the first pixel using data from both the first set and the second set of pixels.

16. The method according to claim 15 further including:  
performing spatial filtering on the first pixel;  
determining a motion component between the first set of pixels and the second set of pixels; and  
carrying out a motion compensator filtering if the first motion component between the first set and the second set is above a selected threshold and not carrying out motion compensation filtering if the motion component between the first set and the second set is below a selected threshold

## ABSTRACT OF THE DISCLOSURE

A method for filtering the noise of a sequence of digital images in CFA format comprising the following phases:

- processing a first CFA image of the sequence to obtain a corresponding improved CFA image with reduced noise;

- processing at least one pixel of a second CFA image of the sequence that temporally follows said first image, said phase of processing at least one pixel providing a corresponding filtered pixel and including the following operations:

  - selecting a first set of pixels comprising said at least one pixel and a plurality of pixels of the second CFA image spatially adjacent to it;

  - selecting a second set of pixels comprising pixels of the improved CFA image homologous with the pixels of said first set;

  - carrying out a digital filtering of a first type using pixels forming part of said first and second set to generate the filtered pixel.

851063.485 / 404798\_1



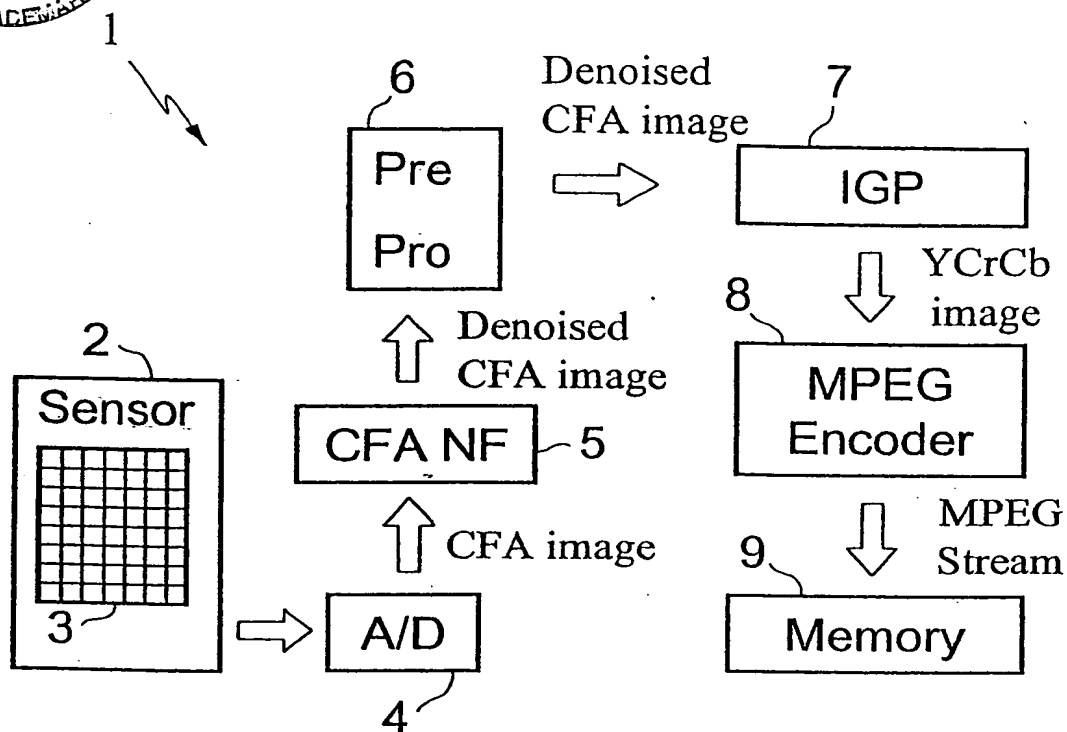
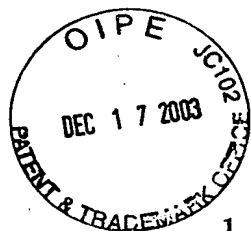


Fig. 1

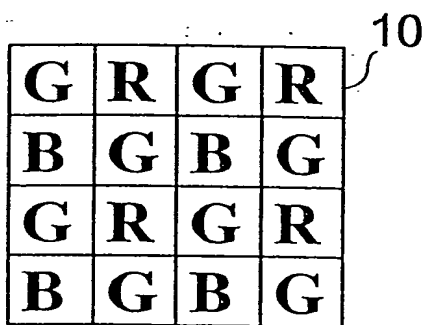


Fig. 2

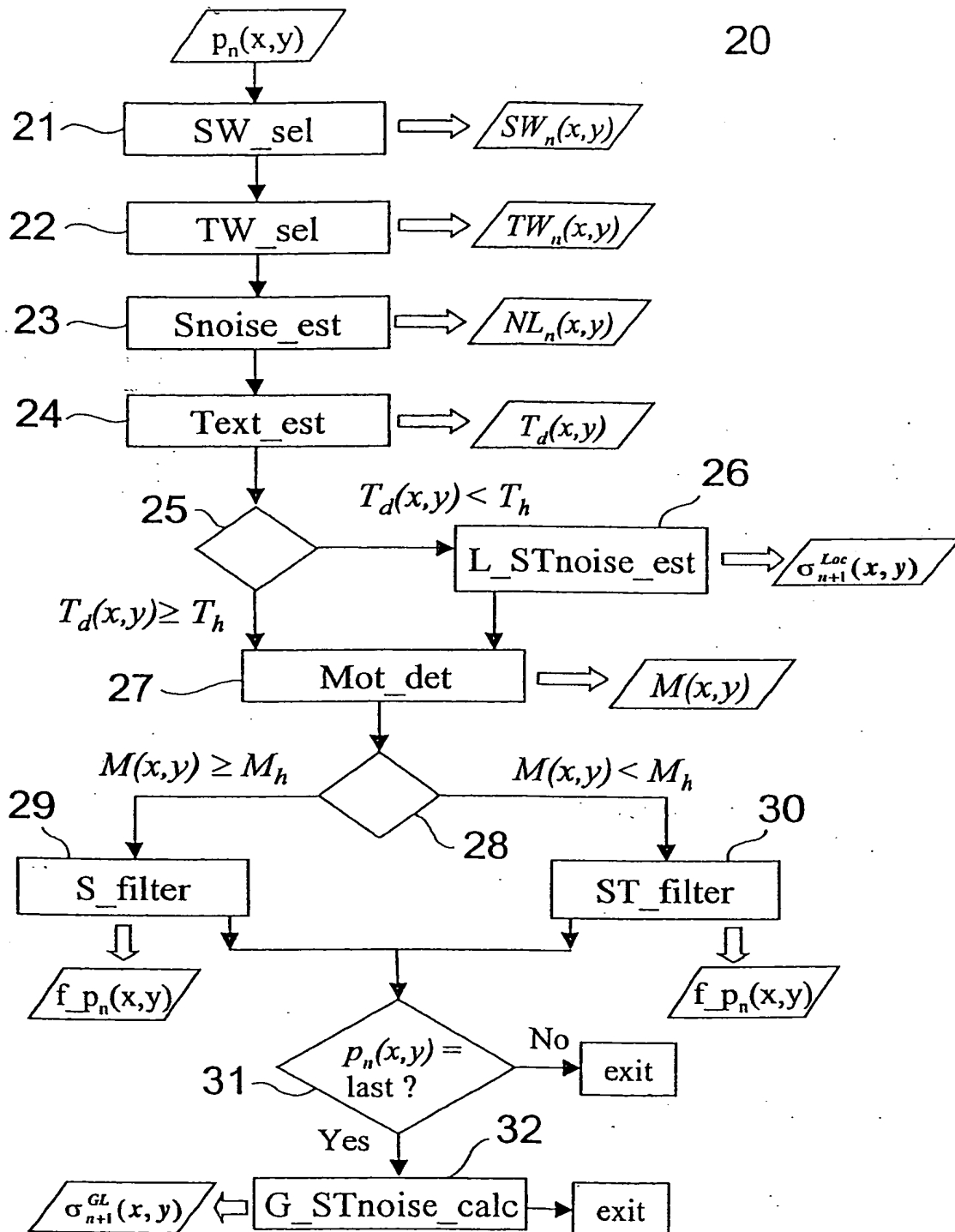


Fig. 3

SM\_G

G	R	<b>G<sub>1</sub></b>	R	G
B	<b>G<sub>2</sub></b>	B	<b>G<sub>3</sub></b>	B
<b>G<sub>4</sub></b>	R	<b>G<sub>0</sub></b>	R	<b>G<sub>5</sub></b>
B	<b>G<sub>6</sub></b>	B	<b>G<sub>7</sub></b>	B
G	R	<b>G<sub>8</sub></b>	R	G

*Fig. 4*

SM\_R

<b>R<sub>1</sub></b>	G	<b>R<sub>2</sub></b>	G	<b>R<sub>3</sub></b>
G	B	G	B	G
<b>R<sub>4</sub></b>	G	<b>R<sub>0</sub></b>	G	<b>R<sub>5</sub></b>
G	B	G	B	G
<b>R<sub>6</sub></b>	G	<b>R<sub>7</sub></b>	G	<b>R<sub>8</sub></b>

SM\_B

<b>B<sub>1</sub></b>	G	<b>B<sub>2</sub></b>	G	<b>B<sub>3</sub></b>
G	R	G	R	G
<b>B<sub>4</sub></b>	G	<b>B<sub>0</sub></b>	G	<b>B<sub>5</sub></b>
G	R	G	R	G
<b>B<sub>6</sub></b>	G	<b>B<sub>7</sub></b>	G	<b>B<sub>8</sub></b>

*Fig. 5*

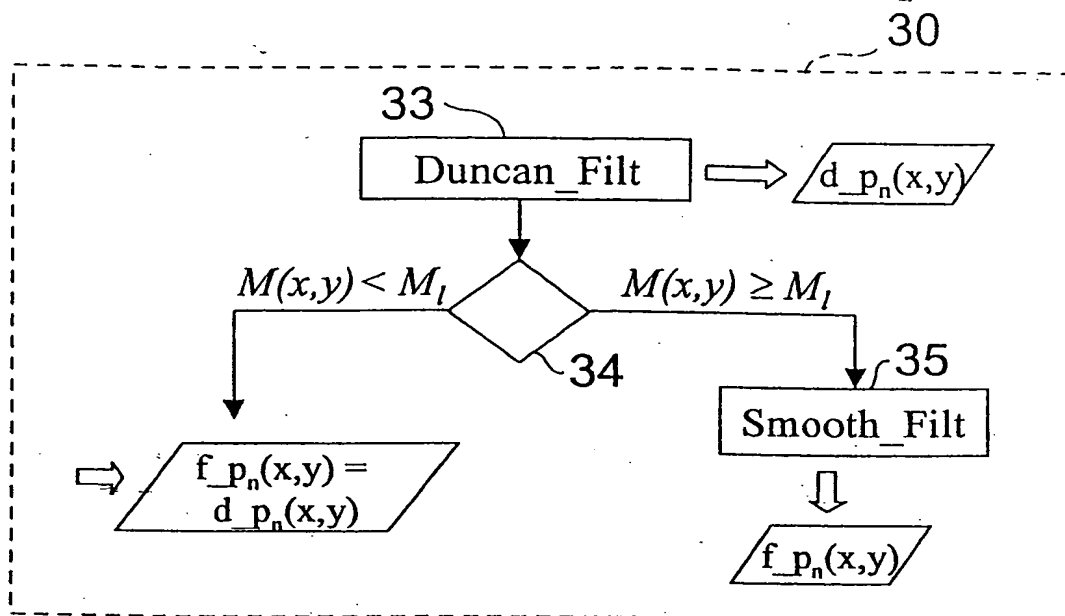


Fig. 6

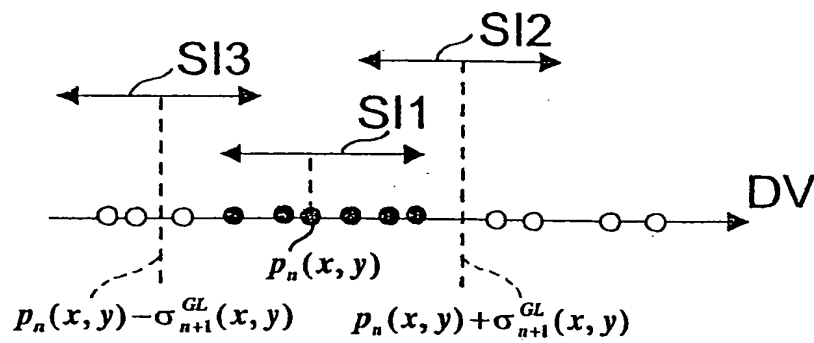
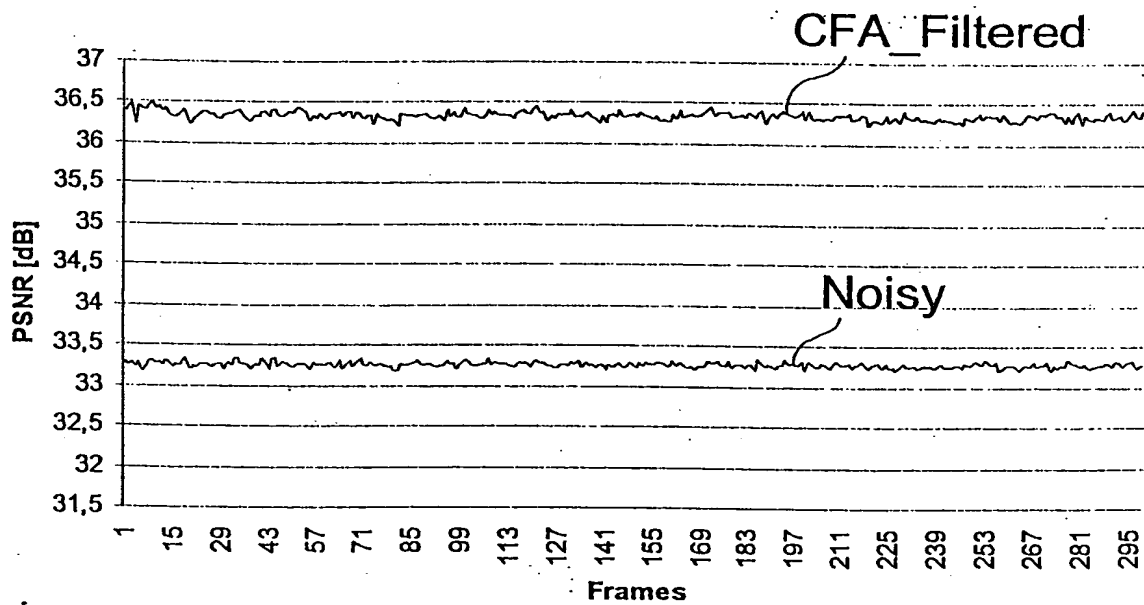


Fig. 7



*Fig. 8*

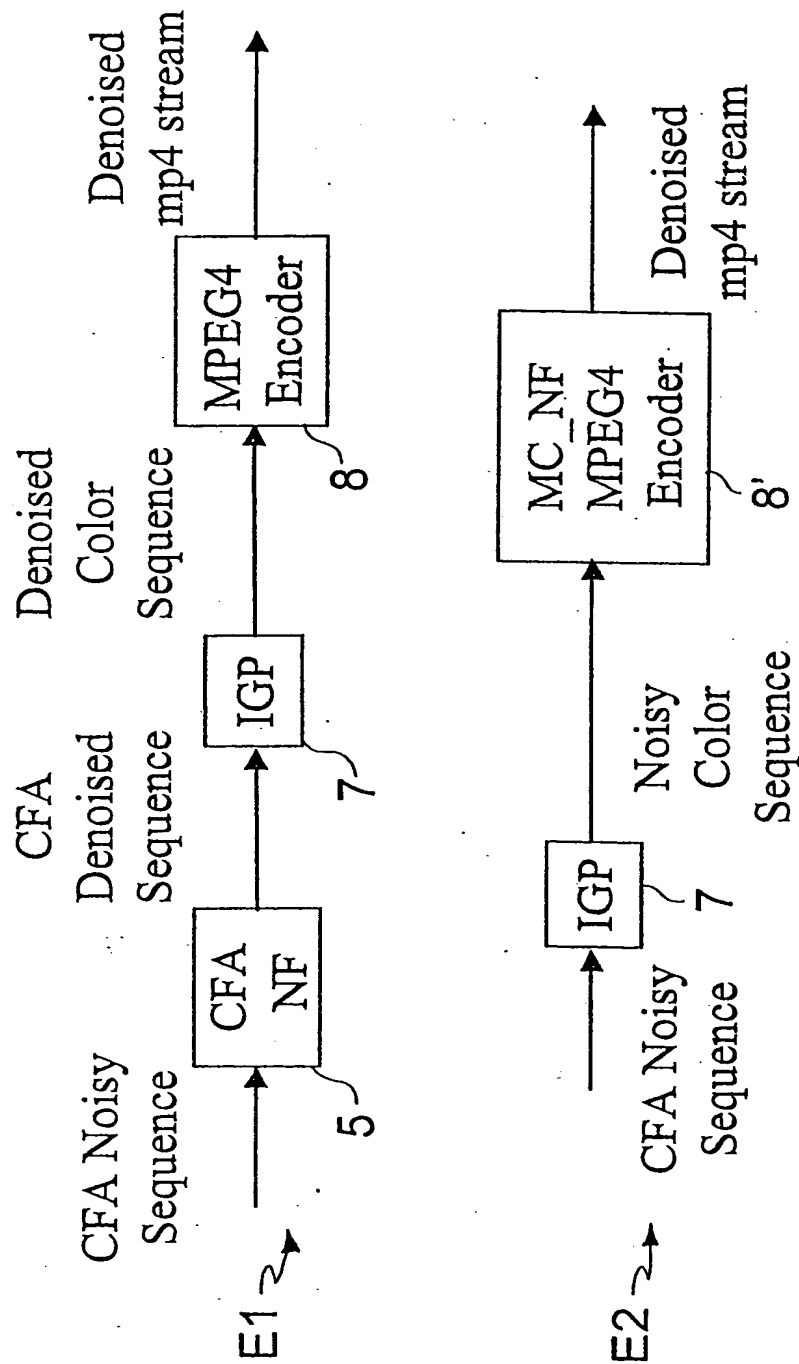
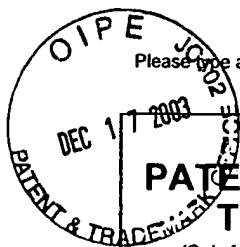


Fig. 9



Please type a plus sign (+) inside this box



PTO/SB/05 (11-00)

Approved for use through 10/31/2002. OMB 0651-0032. U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE  
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

<b>UTILITY PATENT APPLICATION TRANSMITTAL</b> (Only for new nonprovisional applications under 37 CFR 1.53(b))	Attorney Docket No.	851063.485
	First Inventor	Ang lo Bosco
	Title	METHOD FOR FILTERING THE NOISE OF A DIGITAL IMAGE SEQUENCE
	Express Mail Label No.	EV336610850US

1. <input type="checkbox"/> Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original and a duplicate for fee processing)	7. <input type="checkbox"/> CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
2. <input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27.	8. <input type="checkbox"/> Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
3. <input checked="" type="checkbox"/> Specification [Total Pages <u>29</u> ] (preferred arrangement set forth below) <ul style="list-style-type: none"><li>- Descriptive title of the Invention</li><li>- Cross Reference to Related Applications</li><li>- Statement Regarding Fed sponsored R &amp; D</li><li>- Reference to sequence listing, a table, or a computer program listing appendix</li><li>- Background of the Invention</li><li>- Brief Summary of the Invention</li><li>- Brief Description of the Drawings (if filed)</li><li>- Detailed Description</li><li>- Claim(s)</li><li>- Abstract of the Disclosure</li></ul>	a. <input type="checkbox"/> Computer Readable Form (CRF) b. <input type="checkbox"/> Specification Sequence Listing on: <ul style="list-style-type: none"><li>i. <input type="checkbox"/> CD-ROM or CD-R (2 copies); or</li><li>ii. <input type="checkbox"/> paper</li></ul> c. <input type="checkbox"/> Statements verifying identity of above copies
4. <input checked="" type="checkbox"/> Drawing(s) (35 U.S.C. 113) [Total Sheets <u>6</u> ]	<b>ACCOMPANYING APPLICATION PARTS</b> 9. <input type="checkbox"/> Assignment Papers (cover sheet & document(s)) 10. <input type="checkbox"/> 37 CFR 3.73(b) Statement <input type="checkbox"/> Power of (when there is an assignee) Attorney 11. <input type="checkbox"/> English Translation Document (if applicable) 12. <input checked="" type="checkbox"/> Information Disclosure <input checked="" type="checkbox"/> Copies of IDS Statement (IDS)/PTO-1449 Citations 13. <input type="checkbox"/> Preliminary Amendment 14. <input checked="" type="checkbox"/> Return Receipt Postcard (MPEP 503) Should be specifically itemized 15. <input type="checkbox"/> Certified Copy of Priority Document(s) (if foreign priority is claimed) 16. <input type="checkbox"/> Nonpublication Request under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent. 17. <input type="checkbox"/> Other: _____
5. <input type="checkbox"/> Oath or Declaration [Total Sheets <u>1</u> ] <ul style="list-style-type: none"><li>a. <input type="checkbox"/> Newly executed (original or copy)</li><li>b. <input type="checkbox"/> Copy from a prior application (37 CFR 1.63 (d)) (for a continuation/divisional with Box 18 completed)</li><li>i. <input type="checkbox"/> <b>DELETION OF INVENTOR(S)</b> Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).</li></ul>	
6. <input checked="" type="checkbox"/> Application Data Sheet. See 37 CFR 1.76	

18. If a CONTINUING APPLICATION OR APPLICATION CLAIMING FOREIGN PRIORITY, check appropriate box, and supply the  
requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:  
☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) ☒ Claims priority from European application  
No. 02425532.5 filed August 23, 2002

Prior application information Examiner \_\_\_\_\_ Group Art Unit: \_\_\_\_\_  
For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or  
declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or  
divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a  
portion has been inadvertently omitted from the submitted application parts.

19. CORRESPONDENCE ADDRESS			
<input type="checkbox"/> Correspondence address below		or:	
Firm Name		Customer Number  00500	
Address			
City, State, Zip			
Country			
Telephone			
Name (Print/Type)	David V. Carlson	Registration No. (Attorney/Agent)	31,153
Signature		Date	August 12, 2003

Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount  
of time you are required to complete this form should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, Washington, DC 20231. DO NOT SEND  
FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, Mail Stop Patent Application, P.O. Box 1450, Alexandria, VA 22313-1450.

404945

EXHIBIT B

EXTREMELY URGENT Please Rush To Addressee

FOR PICKUP OR TRACKING OF ALL YOUR PACKAGES

Returned  
8/22/03



UNITED STATES POSTAL SERVICE®  
CORPORATE ACCOUNT  
POSTAGE AND FEES PAID

WWW.USPS

HOW TO USE



Addressee Copy  
Label 11-F June 2002



Post Office To Addressee

UNITED STATES POSTAL SERVICE®  
DELIVERY (POSTAL USE ONLY)

ORIGIN (POSTAL USE ONLY)				DELIVERY (POSTAL USE ONLY)			
PO ZIP Code	Date of Delivery	Day of Delivery	Flat Rate Envelope	Delivery Attempt	Time	Day	Month
08139	8/22/03	Mon	<input checked="" type="checkbox"/>	1	10:00 AM	Mon	8
Date in Month	Day	Year	Postage	Delivery Date	Time	Day	Month
8	22	03	\$ 1.00	8/22/03	10:00 AM	Mon	8
Time In	Weight	Int'l Alpha Country Code	Return Receipt Fee	MO. Day	Time	Day	Month
10:00 AM	1.00 lb	000	\$ 0.00	8/22/03	10:00 AM	Mon	8
No Delivery	Insurance Fee	Acceptance Clerk Initials	COD Fee	Employee Signature	Time	Day	Month
<input checked="" type="checkbox"/>	\$ 0.00	000	\$ 0.00	[Signature]	10:00 AM	Mon	8
NO DELIVERY	Total Postage & Fees			Employee Signature	Time	Day	Month
<input checked="" type="checkbox"/>	\$ 1.00			[Signature]	10:00 AM	Mon	8

STANDARD USE ONLY  
POSTAGE PAID  
Post Office Add. No. X980232

FROM: (PLEASE PRINT)		TO: (PLEASE PRINT)	
DAVID V. CARLSON	PHONE 206 622-4900	MAIL STOP PATENT APPLICATION	PHONE
INTELLECTUAL PROPERTY			
1000 1ST AVE STE 600			
SEATTLE WA 98101			
ics 851060-285	08/12/03		

How many boxes

The the

EXHIBIT F

FOR PICKUP OR TRACKING CALL 1-800-222-1811 www.usps.com





EV 336610850 US



UNITED STATES POSTAL SERVICE®

Customer Copy  
Label 11-F June 2002

Post Office To Address

ORIGIN (POSTAL USE ONLY)			DELIVERY (POSTAL USE ONLY)		
PO ZIP Code 98104	Day of Delivery <input type="checkbox"/> Next <input checked="" type="checkbox"/> Second	Flat Rate Envelope <input type="checkbox"/>	Delivery Attempt Mo. Day	Time <input type="checkbox"/> AM <input type="checkbox"/> PM	Employee Signature
Date 8/12/03	<input type="checkbox"/> Noon <input type="checkbox"/> 3 PM	Postage \$	Delivery Attempt Mo. Day	Time <input type="checkbox"/> AM <input type="checkbox"/> PM	Employee Signature
Time In <input type="checkbox"/> AM <input checked="" type="checkbox"/> PM	Military <input type="checkbox"/> 2nd Day <input type="checkbox"/> 3rd Day	Return Receipt Fee \$	Delivery Date Mo. Day	Time <input type="checkbox"/> AM <input type="checkbox"/> PM	Employee Signature
Weight 1 lbs. 3 ozs.	Int'l Alpha Country Code	COD Fee Insurance Fee	<input type="checkbox"/> WAIVER OF SIGNATURE (Domestic Only) Additional merchandise insurance is void if waiver of signature is requested. I wish delivery to be made without obtaining signature of addressee or addressee's agent (if delivery employee judges that article can be left in secure location) and authorize that delivery employee's signature constitutes valid proof of delivery.		
No Delivery <input type="checkbox"/> Weekend <input checked="" type="checkbox"/> Holiday	Acceptance Clerk Initials D	Total Postage & Fees \$ 13.65	<input type="checkbox"/> NO DELIVERY <input type="checkbox"/> Weekend <input type="checkbox"/> Holiday		
CUSTOMER USE ONLY			CUSTOMER USE ONLY		
METHOD OF PAYMENT: Express Mail Corporate Acct. No. X980232			Federal Agency Acct. No. or Postal Service Acct. No.		
FROM: (PLEASE PRINT) DAVID V. CARLSON SEED INTELLECTUAL PROPERTY LAW GROUP PLLC 701 5TH AVE STE 6200 SEATTLE WA 98104-7092 DVC:lcs 851063.485 08/12/03			TO: (PLEASE PRINT) MAIL STOP PATENT APPLICATION COMMISSIONER FOR PATENTS PO BOX 1450 ALEXANDRIA VA 22313-1450		
PRESS HARD. You are making 3 copies. FOR PICKUP OR TRACKING CALL 1-800-222-1811 www.usps.com					



EXHIBIT A



Express Mail No. EV336610850US

851063.485

DVC:lcs

Mail Stop Patent Application  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

SENT: August 12, 2003  
NEW APPLICATION

**PLEASE STAMP WITH APPLICATION NO. AND RETURN**

Kindly acknowledge receipt of the below-listed documents by placing your receiving stamp hereon and mailing:

Form PTO/SB/05; Application Data Sheet; Spec., Claims, Abstract (29 pages); 6 Sheets of Drawings (Figs. 1-9); IDS; PTO-1449; Cited References (4); in re: Angelo Bosco et al., for METHOD FOR FILTERING THE NOISE OF A DIGITAL IMAGE SEQUENCE.

**\*\*NO FEE OR FORMAL PAPERS BEING SUBMITTED\*\***

SEED INTELLECTUAL PROPERTY LAW GROUP PLLC

**Filing Date**  
**Stamp**



**Application**  
**Number**

404944